Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 31 (2012) 240 – 244

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Advances in Computational Modeling and Simulation

Numerical Simulation on Thermal Energy Storage Behavior of Cu/paraffin nanofluids PCMs

Shuying Wu[a*], Hua Wang[a], Song Xiao[a], Dongsheng Zhu[b]

[a]*Faculty of Metallurgical and Energy Engineering, Kunming University of Science and Technology, Kunming, China*
[b]*School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou, China*

Abstract

PCMs have foreseeable applications in residential buildings for effective use of solar energy. Paraffin is cheap and has moderate thermal energy storage density but low thermal conductivity. In this paper, we numerically investigate the melting processes of Cu/paraffin nanofluids PCMs. The results strongly suggested that the phase change heat transfer of paraffin was enhanced due to the addition of nanoparticles. For 1 wt% Cu/paraffin, the melting time can be saved 13.1%. The numerical results have a good agreement with the experimental results in describing the melting phenomena. These results show that adding nanoparticles is an efficient way to enhance the heat transfer in latent heat thermal energy storage system.

Keywords: Melting; paraffin; Cu nanoparticles; phase change materials(PCMs)

1. Introduction

The continuous increase in the level of greenhouse gas emissions and the climb in fuel prices are the main driving forces to effectively utilize various sources of renewable energy [1]. One of prospective techniques of storing solar energy is the application of PCMs. Among lots of PCMs, paraffin has been considered most valuable due to desirable characteristics, including large latent heat capacity, negligible

* Corresponding author. Tel.: +86 -871-515-3405; fax: +86-871-515-3405.
E-mail address: wushuying5876@126.com

doi:10.1016/j.proeng.2012.01.1018

super cooling, good thermal and chemical stability and so on. However, the inherent low thermal conductivity (0.21-0.24W/mK) strongly hinders its widely implication [2].

Recently, with the development of nanotechnology, researchers have started to study the thermal conductivity performance of adding nanoparticles to various fluids, so-called "nanofluids", which can result in the thermal conductivity enhancement being significantly higher than the predictions of the classical solid-liquid models. Many experimental results [3-6] have reported that the addition of nanoparticles could enhance the heat transfer of PCMs. In this work, the computational study of nanoparticle-enhanced phase change material for thermal energy storage application is presented.

2. Mathematical Formation

Considering a two-dimensional enclosure cavity filled with PCMs and air. In the initial state, there was 2.5 cm height of PCMs and 1 cm height of air in the cavity. The top of the cavity is enclosed and taken by air. The "volume-of-fluid" (VOF) model was used to describe the PCM-air system with a moving interface but without inter-penetration of the two media [7]. The wall of the cavity is glass with 2 mm thick. The length and height of the cavity were 6 cm and 3.5 cm, respectively. PCMs in the cavity are Newtonian, incompressible, and laminar. Thermophysical properties of PCMs are assumed to be constant, whereas the density variation in the buoyancy force is based on the Boussinesq approximation. The nanoparticles are assumed to have a uniform shape and size. The lower left corner of the cavity was the origin of the coordinate system. The gravity vector was directed in the negative x_2 coordinate direction, g_{x_1} = 0 and g_{x_2} = g.

The thermophysical properties are given in Table 1. The properties of air and glass used for computation are given in Table 2. The present processing method can be found elsewhere [8].

Table 1 The thermophysical parameter of the copper nanoparticles, paraffin and Cu/paraffin(1 wt%)

	Cu	Paraffin	Cu/paraffin(1 wt%)
ρ(kg/m^3)	8954	900（T=329 K） 773（T=333 K）	908（T=329 K） 781（T=333 K）
c_p(J/kg·K)	383	2950（T=329 K） 2464（T=333 K）	2924（T=329 K） 2390（T=333 K）
k(W/m·K)	400	0.2699（T=329 K） 0.1687（T=333 K）	0.2908（T=329 K） 0.1878（T=333 K）
T_m(K)		329~333	329~333
$\hbar$(kJ/kg)		205.6	183.9
μ(Pa.s)		0.03	0.03
β(1/K)	$1.67*10^{-5}$	$5*10^{-4}$	$4.95*10^{-4}$

Table 2 Properties of air and glass used for computation

	k(W/m·K)	ρ(kg/m^3)	c_p(J/kg·K)
Air	0.0242	$1.2*10^{-5}T^2$-0.01134T+3.498	1006.4
Glass	0.81	2500	670

3. Numerical Methods

The simple method within Fluent 6.2 software was used to solve the governing equations. The uniform grid spacings for both x_1 and x_2 directions were utilized. The time step for integrating the temporal derivatives was set to 0.01 s, following comparison of selected quantities obtained from simulations using 0.1 s, 0.01 s and 0.001 s. The Quick differencing scheme was used for solving the momentum and energy equations, whereas the Presto scheme was adopted for the pressure correction equation. The under-relaxation factors for the velocity components, pressure correction, thermal energy and liquid fraction were 0.5, 0.3, 1 and 0.9, respectively. The residual convergence criterion for the energy equation was set to 10-7, and convergence had been ensured at every time step.

4. Results and Discussion

4.1. Melting of the PCM

The initial temperature of PCMs and glass wall was 303 K and 343 K, respectively. The wall temperature kept constant. Colorized contours of the isothermal distribution of paraffin and 1 wt% Cu/paraffin are shown in Fig. 1. The time intervals are 633 s, 1002 s and 1398 s. It is found that the

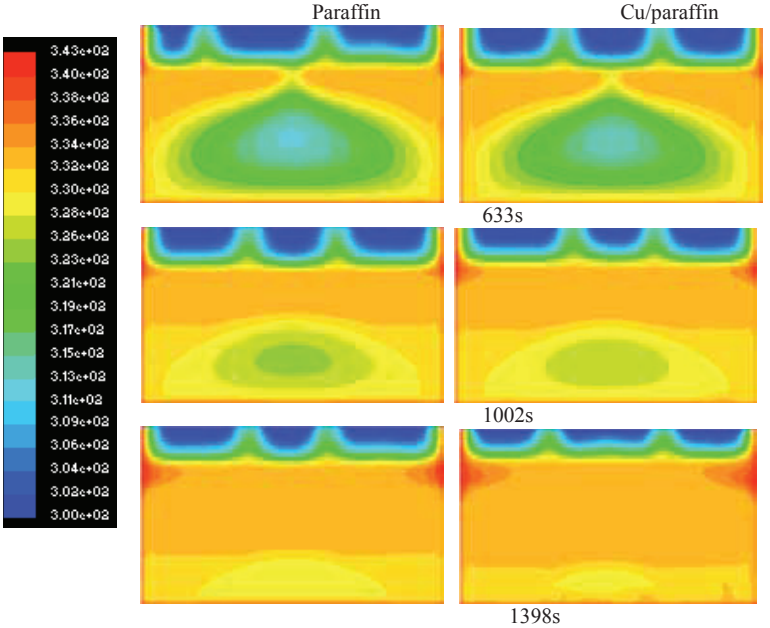

Fig. 1 The isothermal distribution at various time instants

temperature distribution rate of Cu/paraffin is quicker than that of paraffin, which indicates that the addition of Cu nanoparticles accelerates the melting of paraffin. The numerical results have a good agreement with the experimental results [9].

A higher rate of melting near the top of the cavity was found due to the effect of natural convection in the molten PCM. In the early stage of melting, the velocity of the liquid PCM due to the buoyancy force is small. It increases and becomes dominant until the magnitude of the velocity begins to decrease due to the temperature difference in the liquid PCM becoming more uniform [10].

The possible reason of the quicker melting rate is the higher thermal conductivity of Cu/paraffin [9]. At the process of melting, large amount of heat will be charged. If the heat couldn't be absorbed timely, the melting process will be delayed. After adding the nanoparticles to paraffin, PCMs have higher thermal conductivity. Therefore, the melting rate of PCMs is able to be accelerated.

4.2. The comparison between experimental and numerical results.

Fig. 2 is the thin liquid layer in the below wall. In order to verify the numerical result, the melting process of paraffin was recorded by the digital camera, shown in Fig. 3. Compared with Fig. 2, it shows that there is a good agreement of the melting phenomenon between experimental and numerical results, such as convection in the liquid phase, volumetric expansion due to melting, sinking of the solid in the liquid and close-contact-melting. Due to the density change between solid and liquid phase, paraffin always keeps the close-contact-melting during the process. In addition, the melting rate in the upper is quicker than that in the lower. That is due to the natural convection caused by the sinking solid phase, which makes the liquid phase rising along the wall and moves towards the center of the beaker.

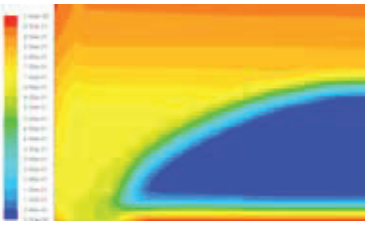

Fig. 2 Thin liquid layer in the below wall with numerical method

Fig. 3 Melting photograph of paraffin with experimental method

4.3. The instantaneous liquid volume

The instantaneous dimensionless volume of PCMs within the cavity, i.e.:

$$\text{Liquid Volume}(t) = \int_{x=0}^{H}\int_{y=0}^{H} \lambda(x,y,t)\mathrm{d}x\mathrm{d}y/H^2 \tag{1}$$

is presented in Fig. 4. The whole melting time of pure paraffin and Cu/paraffin is 3209 s and 2870 s, respectively. It reveals that the time of the phase change heat transfer was saved because of the addition of nanoparticles. This is due to the enhanced thermal conductivity of Cu/paraffin in comparison to that of paraffin. At the same time, due to lowering of the latent heat of fusion, less energy per unit mass of Cu/paraffin is needed for phase change. This phenomenon is in agreement with the study of Liu[4], who experimentally investigated $TiO_2/BaCl_2$-H_2O suspensions for thermal energy storage.

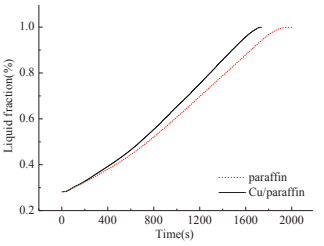

Fig. 4 Instantaneous volume of liquid PCMs

5. Conclusions

The melting process of Cu/paraffin nanofluids as a new PCM was numerically investigated in this study. Probably due to the enhancement of thermal conductivity, the melting rate of paraffin is enhanced after adding Cu nanoparticles. Adding 1 wt% Cu nanoparticles, the melting time of paraffin can be saved by 13.1%. The numerical results have a good agreement with the experimental results, including convection in the liquid phase, volumetric expansion due to melting, sinking of the solid in the liquid and close-contact-melting.

Acknowledgements

The authors would like to acknowledge the Application of Basic Research Projects of Yunnan (Grant number 2011FZ032).

References

[1] Patrice P, Cynthia CA, Ian BM, Adam W. A review of available methods for seasonal storage of solar thermal energy in residential applications. *Renew Sust Energ Rev* 2011; **15**: 3341-59.

[2] Farid MM, Khudhair AM, Razack SAK, Al-Hallaj S. A review on phase change energy storage: materials and applications. *Energ Convers Manage* 2004; **45**:1597-1615.

[3] Ho CJ and Gao JY, Preparation and thermophysical properties of nanoparticle-in-paraffin emulsion as phase change material. *Int Commun Heat Mass Transfer* 2009; **36**: 467-70.

[4] Liu YD, Zhou YG, Tong MW, et al., Experimental study of thermal conductivity and phase change performance of nanofluids PCMs. *Microfluid Nanofluid* 2009; **7**: 579-84.

[5] Zeng J, Cao Z, Yang D, et al. Thermal conductivity enhancement of Ag nanowires on an organic phase change material. *J Therm Anal Calorim* 2010; **101**: 385-89.

[6] Wang JF, Xie HQ, Xin Z. Thermal properties of heat storage composites containing multiwalled carbon nanotubes. *J Appl Phys* 2008; **104**: 113537.

[7] Assis E, Katsman L, Ziskind G, et al. Numerical and experimental study of melting in a spherical shell. *Int Commun Heat Mass Transfer* 2007; **50**: 1790-1804.

[8] Khodadadi JM, Hosseinizadeh SF, Nanoparticle-enhanced phase change materials (NEPCM) with great potential for improved thermal energy storage. *Int Commun Heat Mass Transfer* 2007; **34**: 534-43.

[9] Wu SY, Zhu DS, Zhang XR, et al. Preparation and melting/freezing characteristics of Cu/Paraffin nanofluid as phase-change material (PCM). *Energ Fuels* 2010; **24**: 1894-8.

[10] Pal D, Joshi Y. Melting in a side heated enclosure by uniformly dissipating heat source. Int J Heat Mass Transfer 2001; 44: 375-87.